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Introduction

On March 21, 1960, Mr. G.M Webb, Traffic Engineer, requested that a report be issued covering the investigational results and requirements found necessary to control the green background color employed on illuminated highway signs in California.

Because color involves psychological and psychophysical effects, much of the initial selection was based upon jury reaction. The depth of the color employed (color contrast to the legend) is the only control which has definite physical significance. As a means of establishing a permanent record and evaluation of the jury selected color and permissible parameters, the factors have been expressed in physical terms using the National Bureau of Standards Tri-Stimulus Coefficients which can denote color value, luminous apparent reflectance and spectral gloss.

Since the National Bureau of Standards technique of color evaluation by the Tri-Stimulus tri-coordinate methods is extremely involved, as a practical matter sample color chips or color standards will be required by both industry and highway inspectors to control production and set permissible parameters. Information is provided regarding these standards.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

STANDARDIZATION OF THE BACKGROUND GREEN COLOR FOR ILLUMINATED HIGHWAY SIGNS

60-05

April 1960

State of California
Department of Public Works
Division of Highways
Materials and Research Department

April 1960

Mr. G. M. Webb
Traffic Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is a report covering:

STANDARDIZATION OF THE BACKGROUND GREEN COLOR

FOR ILLUMINATED HIGHWAY SIGNS

Study made by . . . . . Structural Materials Section
Under general direction of . . . . . J. L. Beaton
Work supervised by . . . . . R. N. Field
Tests conducted by . . . . . J. E. Barton and R. L. Donner
Report prepared by . . . . . R. N. Field and L. S. Hannibal

Very truly yours,

F. N. Hveem
Materials and Research Engineer

RNF/LSH/JLB:mw
cc: Districts
Hdqtrs. Depts.

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INTRODUCTION

On March 21, 1960, Mr. G. M. Webb, Traffic Engineer, requested that a report be issued covering the investigational results and requirements found necessary to control the green background color employed on illuminated highway signs in California.

Because color involves psychological and phycho-physical effects, much of the initial selection was based upon jury reaction. The depth of the color employed (color contrast to the legend) is the only control which has definite physical significance. As a means of establishing a permanent record and evaluation of the jury selected color and permissable parameters, the factors have been expressed in physical terms using the National Bureau of Standards Tri-Stimulus Coefficients which can denote color value, luminous apparent reflectance and spectral gloss.

Since the National Bureau of Standards technique of color evaluation by the tri-stimulus tri-coordinate methods is extremely involved, as a practical matter sample color chips or color standards will be required by both industry and highway inspectors to control production and set permissable parameters. Information is provided regarding these standards.

SUMMARY

Standardization of the background green color has been established for illuminated green enameled interstate signs in California. The color was selected by jury evaluation of variants in the "Standard Interstate green color" as modified so that a suitable background contrast could be maintained to retain clarity of legend. Since fired porcelain enamels are subject to minor color differences due to variations in blends of frit, thickness of the enamel coat, and firing techniques as well as color aging, a reasonable degree of color variation must be tolerated. For standard reference purposes tri-chromatic coordinates and luminous apparent reflectance values were established for this range as given below (the coordinates are also shown in graphical form on Exhibit I in the Appendix):

	x	y	"Y"
Minimum	.23	.36	.03
Mid-range	.25	.39	.05
Maximum	.27	.42	.07

Such measurements were taken with a Photovolt Model 610 reflectometer using a Model 660 - 45 degree search head. Readings are made in accordance to the National Bureau of Standards circular C 429 using the NBS S-reflectance standards SCR-11 as primary references.

The above tri-stimulus values represent a reproducible strict physical standard basic evaluation. Commercial practices and daily production techniques require a color chip for control purposes. Munsell or Bowles color standards which are on treated paper are suggested since these reference standards can be formulated to close tolerances, and are not encumbered by the production variations which plague color control in the porcelain enamel on metal industry. This latter factor makes close tolerance enamel color chips a difficult and expensive item to produce. Four by six inch (4" x 6") and two by three inch (2" x 3") standards on treated paper as outlined above could be used for day to day control.

A luminant reflectance ratio* of ten to one (10:1) in foot lamberts as measured by portable spectra brightness meters has been a minimum standard of contrast for sign legend as compared to background color for some years in California. Such a contrast is necessary to maintain clarity of legend at night. The luminant reflectance ratio is not completely identical with the luminous apparent reflectance* ratio of the legend to background, but the magnitudes of reflectance have been found sufficiently similar to permit the same 10 to 1 ratio to be adopted. Since the average "Y" value (luminous apparent reflectance) for

white porcelain enamel legends has been found to be approximately 0.734 for existing production run material, the application of this 10 to 1 ratio is in agreement with the "Y" value of 0.070 given above for the maximum acceptable tri-stimulus standard value established for the background green luminous apparent reflectance.

* Footnote:

Since there are several ways of expressing light reflectance and light contrasts, the terminology used in this report must be defined rather carefully as follows:

Brightness or brightness ratio, an older term for luminant values or luminant ratios as measured with a spectra brightness meter in foot lamberts.

Luminous apparent reflectance is apparent reflectance weighted according to the luminosity function and is designated as the "Y" term in tri-stimulus values.

The reflectance ratio of two colors are approximately the ratios of the "Y" values for each color sample.

Specular gloss is that light reflected from the surface of a material and is comparable to the reflectance of light by a mirror.

CONCLUSIONS AND RECOMMENDATIONS

Selected porcelain enamel color chips, if obtainable within the tolerances desired, can be employed as primary color standards for highway signing. However, alkyd resin or alkyd urea sprayed enamels are acceptable as standards provided that the proper characteristics can be obtained to match porcelain enamel.

Primary standard color chips should be made as near as possible to the mid-range of the desired color values specified. For absolute reference values both the mid-range and parameters should be measured and expressed in National Bureau of Standards C 429 tri-chromatic coordinates (x and y) and the luminous apparent reflectances "Y" as given in the attached table. The spectral gloss ratings of all color standards are to be between 68 and 77 as determined by ASTM procedure D-525-53T.

The mid-range primary standard should be employed by paint manufacturers and porcelain enamel sign manufacturers to establish the desired colors and color depth. The parameter values should be employed for reference inspection purposes only and used as a means of determining an absolute degree of acceptable deviation or tolerance which may be permitted to the manufacturers. Deviation beyond these tolerance values should be cause for rejection of signing material.

A one month aging period of the color chips before use should be employed to eliminate the effects of initial color drift of the sign pigments.

Standard color chips on metal should be four x four inch size (4" x 4") although other larger sizes represent no inconvenience.

RECOMMENDED N.B.S. TRI-STIMULUS COORDINATES FOR PRIMARY COLOR STANDARD AND PARAMETERS OF INTERSTATE GREEN SIGNS

	Tri-Stimulus Coefficients		
	x	y	"Y"
Primary Standard (Mid-Range)	.25	.39	.05
Minimum Values	.23	.36	.03
Maximum Values	.27	.42	.07
Parameter Coordinates	.23	.36	.03
	.23	.36	.07
	.23	.42	.03
	.23	.42	.07
	.27	.36	.03
	.27	.36	.07
	.27	.42	.03
	.27	.42	.07

Testing to determine the above coordinates to be performed according to the National Bureau of Standards, Procedure C 429 using N.B.S. S-Reflectance Standards No. SCR-11 as primary references.

DISCUSSION

1. Tri-Stimulus Equipment

Several physical means have been developed to measure and permanently record colors, color composition, reflectance intensities from colored surfaces, and otherwise reduce what the eye sees psychologically to physical terms. In a number of respects the human eye is far better than instruments in recognizing color or color variations, but not all eyes can define or see the same colors in the same manner. Especially in reference to reflectance intensities or evaluation the eye is a relatively poor instrument. The photoelectric cell can detect intensity variations some thousand-fold smaller than the human eye.

Since the Materials and Research Department possesses a Photovolt reflectometer having a complete set of photoelectric search heads, it was logical to adopt a primary standard photoelectric system amenable to the equipment and to recognize the procedures of the National Bureau of Standards. For that reason the tri-stimulus process which employs the N.B.S. tri-chromatic coordinates to express color, color depth, and light reflectance was a natural selection as a means to physically evaluate and record the green color employed for illuminated signing background. These physical evaluations are strictly electro-optical measurements but give a permanently recordable and accurate means of evaluating the colors involved. The technique of the measurements is covered in the National Bureau of Standards Bulletin C-429 on tri-coordinate color techniques and measurements. A set of N.B.S. SCR-11 S-chromatic reflectance standards are required as an integral part of the test equipment.

The physical measurements and the coordinate system are seldom used in daily commercial practices, thus the tri-coordinate values must be augmented by high quality standard color chips to permit physical matching and comparisons by eye. The requirements concerning color chips is discussed below.

2. Tri-Stimulus Measurements

Tri-stimulus measurements are performed with a Model 610 Photovolt reflectance meter using a 660 - 45° search head having amber, blue, and green filters. Readings as stated above are taken in accordance with the National Bureau of Standards Circular C-429 using the N.B.S. SCR-11 S-chromatic color reference standards. The tri-chromatic coordinates specify color in terms of mixtures of theoretical "basic" colors of amber, green, and blue. Certain correction factors have to be applied to the initial filtered readings to express the color values in standard x and y

coordinates. The "Y" value represents the luminous apparent reflectance which is the apparent lightness (or grey depth) obtained through the green filter alone. An example of the calculations is given in the Appendix.

The mid-range tri-stimulus values given in the specifications for the illuminated sign green enamel when compared to the Munsell color system have an average hue and chroma value near Munsell color 7.5G3/4.

Tri-stimulus measurements can be employed to evaluate oil base or alkyd resin paints, colored plastics, fabrics or other colored materials as well as porcelain enamel. The measurements are not completely applicable to reflective sheeting containing beaded material since the beads function as a combination mirror and light focusing device which approaches a condition comparable to that of specular gloss reflectance.

Tri-stimulus values represent a permanent primary reference standard expressed in rather abstract physical terms. The values can be converted to the ordinates of other color measurement systems, but being highly technical are not employed in daily practice by pigment and paint mixing firms.

3. Sign Legibility

Legibility of a sign legend and the speed at which it can be recognized depends upon the contrast between the sign letters and the sign background. Under adequate nighttime illumination an acceptable ratio of the luminant brightness between the legend and the background color in foot lamberts should be in the order of ten to one to produce an easily read sign. Rations of 20 to 1 are obtainable under ideal conditions, but with the accumulation of dust or dirt or due to variables existing in the degree of illumination such an ideal contrast is hard to maintain. Thus from the practical standpoint a 10 to 1 ratio represents a logical minimum contrast value and such a value has become a recognized minimum standard luminant ratio for signing with the California Division of Highways.

The luminant ratio, which to date has been measured by a portable spectra-brightness meter in foot lamberts, is not normally equal to the luminous apparent reflectance values since the first represents the full spectral reflectance and the latter only that light which is passed by a green filter and is evaluated in the tri-stimulus terms of "Y". Measurements of two existing signs gave the following comparative results:

	Roseville Freeway at Watt Avenue	West Sacramento
Letters, Y_1 value	.734	.734
Background, Y_2 value	.106	.062
Luminous reflectance ratio $\frac{Y_1}{Y_2}$	7	13
Spectra brightness luminant ratio as field measured	7	13

These values are sufficiently significant with the particular green being employed to permit ready adoption of the 10 to 1 apparent reflectance ratio between legend and background. Altogether it is unusual to adopt a luminous reflectance standard similar to the 10 to 1 spectra brightness ratio.

It is to be noted that in the above tabulation the "Y" value for the white enamel letters is given as 0.734. This value has been found to be the average value for production run white enamel legend letters used in highway signing. In applying the 10 to 1 ratio the "Y" value of the background color should not exceed 0.070. This relationship and condition of contrast is the basic reason for not accepting a green background with a lighter shade than 0.070 Y.

4. Color Selection

The initial selection of the background green color for the illuminated signs was aimed at having a color contrast greater than 10 to 1 for legibility and a shade of green that was pleasing to the eye. Visual examination and jury selection of a number of color chips and sample signs of 0.070 Y or greater color depth were conducted under controlled conditions of illumination.

Sample color chips were also arranged in accordance to tri-stimulus values as listed in Exhibit III and illustrated in Exhibit II. From this information it was found that some porcelain enamel shadings would require considerable experimental effort to be produced and that other shades were prone to slight color drift with aging. A desired color range was then selected which would permit industry to employ existing frit formulation and firing processes. Thus the parameters established are not unduly restrictive for industrial production purposes, but some trials are required to formulate a good frit mixture which approaches the mid-range standard desired in all three values: x, y, and "Y".

A production color currently available at the time of preparing this report has a rating approaching:

$$x = .230 + .01$$

$$y = .395 \pm .01$$

$$\text{"Y"} = .050 \pm .01$$

The amber-blue value of x is borderline, but in terms of y and "Y" the samples are near perfect.

5. Color Chips and Samples

Munsell* color sheets by water color process, size 8½x11 inches, or Bowles* color plates (by spray paint process) size 4 x 6 inches can be obtained to rather exacting color values and be used as subprimary standards. Both are on coated paper. The Munsell sheets cost about $25 each and Bowles $50 a hundred. Bowles are made by eye matching only from a sample standard.

Such sheets or plates can be cut to reduced sizes. These samples must be kept in light-tight envelopes to maintain color quality. These chips can be employed as primary standards if the tri-stimulus coordinates agree with the specifications. It must be recognized that the color vehicle containing the pigments is not identical to the porcelain enamel base of the signs, but color and gloss values can be made quite realistic.

High standard or good porcelain enamel color chips are extremely difficult to produce with consistent color control. Slight color variations exist within the frit. The thickness of the base coat and enamel color coat and firing temperatures likewise influence color quality. Finally a number of the colors drift perceptibly with age as well as exposure to sunlight.

Given an adequate set of primary color standards, the porcelain enameling industry can eventually duplicate exactly the colors desired, but it is a slow trial and error process.

A practical method to produce porcelain enamel color chips is to shear up large enameled sheets for selected quality. Aluminum and not steel sheets should be employed for this service as the steel cannot be sheared. Particular care must be taken to avoid slight warpages of the surfaces in order to keep the photoelectric search unit from reporting erroneous results in reflectance and gloss.

* Footnote:

Addresses: Munsell Color Co., Inc., 10 East Franklin Street, Baltimore 2, Maryland.

Bowles Printing Corp., 75 3rd Street, San Francisco, California

An investigation of a regular production run porcelain enamel sign sheared into 30 four by four inch (4" x 4") pieces gave the following color consistency:

	x	y	"Y"
Average	.23	.39	.05
Maximum	.24	.40	.05
Minimum	.22	.38	.05

These deviations are possibly significant to a trained eye, but due to the uniformity of "Y" are not too noticeable at a distance in multiple panel signs.

The Bureau of Standards SCR-11 color reflectance standards are porcelain enamel on four by four inch (4" x 4") x 16 gage steel plates having one quarter inch (¼") crimped edges to prevent surface warpage. Special permanent colors are employed. The crimped edge arrangement produces an ideal base for primary reference standards used directly in tri-stimulus measurements but is an inconvenience for color matching in a production plant. Two by three inch (2" x 3") chips are the minimum permissable size to use with photoelectric search units; four by four inch (4" x 4") are recommended and preferred.

6. Specular Gloss

Specular gloss is a characteristic of the surface finish reflectance and is comparable to light reflectance from a perfect mirror. In such an instance the incident angle of the light source is equal to that of the reflected light. For highly glossed surfaces, a 45° search head is employed, and for low glosses a 60° unit can be employed. ASTM Procedure D-523-53T outlines the procedure. For porcelain enamel tests the Photovolt equipment previously described can be employed with a 660A-60 degree specular gloss head. A black carrara glass mirror with a value of 56 is used as primary reference standard. A National Bureau of Standards G-142 Specular Gloss tile set is employed to obtain readings over the extended specular gloss scale.

The desirable gloss tolerance should be 68 to 77 matte finish according to current specifications and Mr. Webb's report, "Sign Illumination", dated May 29, 1959. Preliminary Interstate green enameled samples examined showed a range of 69 to 83 wherein the larger values are significantly higher than the desired maximum value.

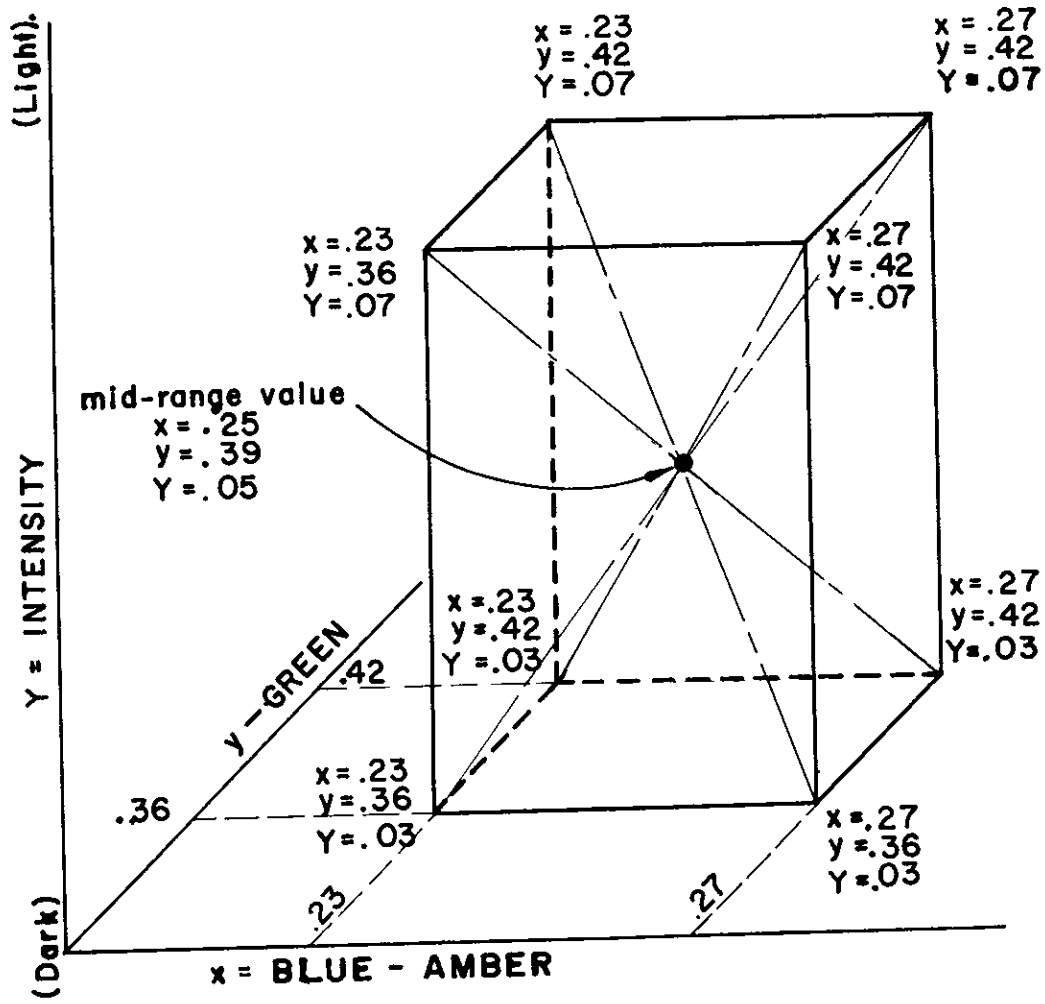
BIBLIOGRAPHY

Munsell Book of Color	Munsell Color Company Baltimore, Maryland
Handbook of Colorimetry	A. H. Hardy, 1936 Massachusetts Institute of Technology
Photoelectric Tri-Stimulus Colorimetry with Three Filters	Circular C-429 National Bureau of Standards 1942
Federal Specifications Interim Revision DD-P-386 of Pipette, Ostwald, Ostwald	Falin, & Ostwald - Van Slyke
Tri-Stimulus Specification of the Munsell Book of Color	K. L. Kelly, et al Circular RP1549 National Bureau of Standards 1943

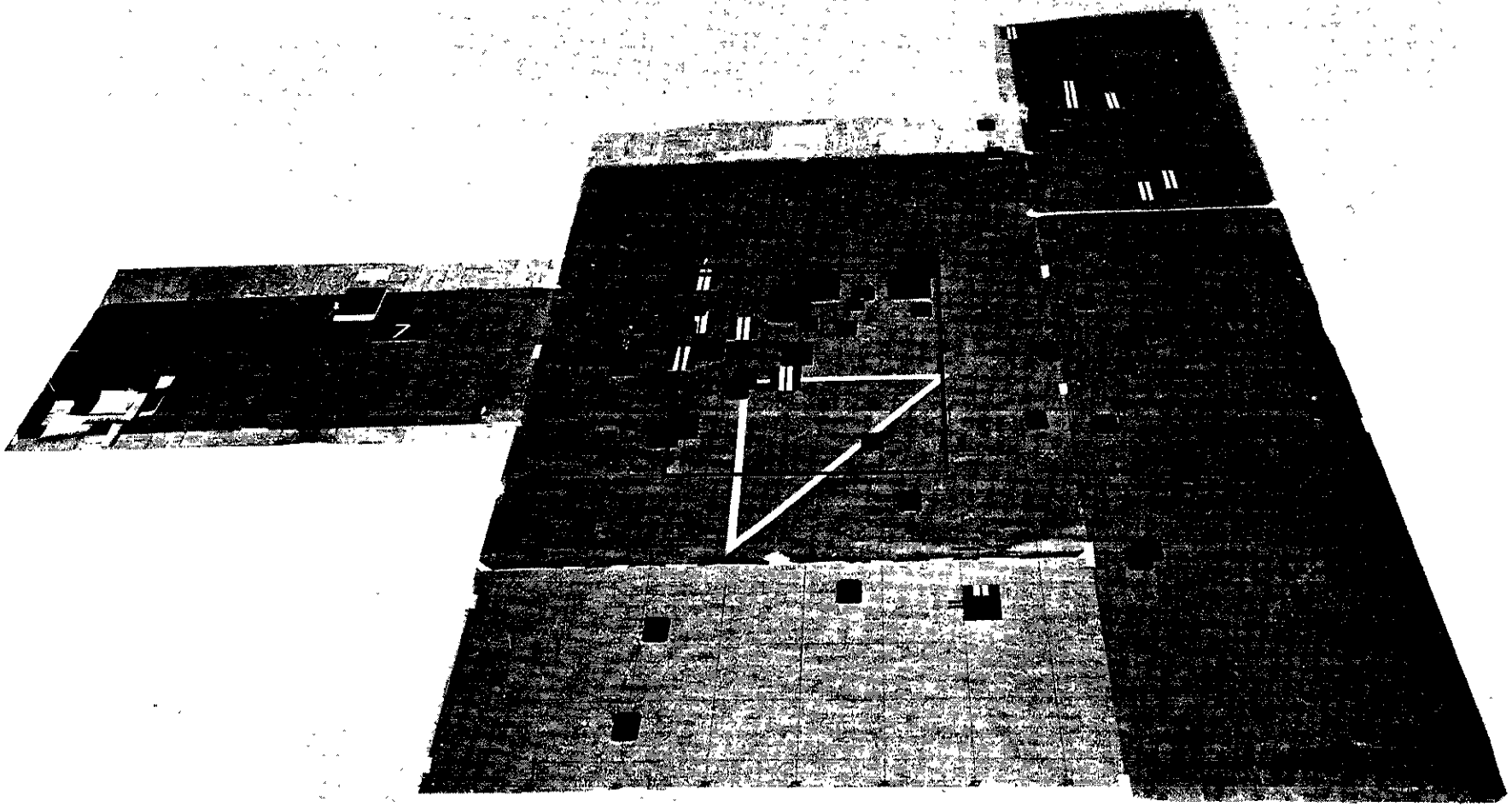
APPENDIX

Exhibit I	Isometric view showing suggested specification mid-range and parameters in terms of tri-stimulus values.
Exhibit II	Color chip selection by coordinates.
Exhibit III	Tri-stimulus values of group of color chips subjected to analysis.

EXHIBIT I



Isometric View : Showing Mid-range Value And Surrounding Parameters In Terms Of Tri-Stimulus Values



COLOR CHIP SELECTION: The rectangle sets the x and y coordinates; the triangle represents an early suggestion which was found too restrictive.

EXHIBIT II

TABLE A

TRI-STIMULUS VALUES OF GROUP OF COLOR CHIPS

SUBJECTED TO ANALYSIS

SAMPLE	VALUES		LUMINOUS APPARENT REFLECTANCE
	x	y	"Y"
8027-BA	.241	.416	.081
4A	.265	.422	.062
4D	.246	.421	.048
8080A	.256	.412	.0510
8104-BA	.249	.406	.059
8025-BA	.231	.402	.068
8150-BA4	.238	.369	.045
8150-BA3	.241	.400	.046
8080-1	.242	.387	.1227
8026-BA	.228	.395	.065
8112-BA	.255	.404	.033
8150-BA2	.232	.378	.042
8150-BA1	.231	.380	.044
8094 (Purchased Sign)	.240	.383	.0832
8091 Initial Standard	.248	.394	.0479

For relative placement of chips, see Exhibit II